The Physics Education Technology Project:
A New Suite of Physics Simulations

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PhET Project Overview:

The Physics Education Technology (PhET) Project is a suite of online tools for teaching and learning introductory physics at the high school and college levels.

- Elaborate Java- and Flash-based simulations.
- Support for educators and students with resources for both teaching and learning with these simulations.
- Research to formally assess their influence on student learning and attitudes in a variety of settings.
- A large number of physics-related simulations exist and are being used in introductory physics courses around the country. In our efforts, we employ a design philosophy that compliments the other simulations available.

During the spring of 2003, several PhET simulations were incorporated into the curriculum for The Physics of Everyday Life - a distribution course for non-science majors. Out initial experience with incorporating the PhET simulations into the classroom curriculum was very positive. As the instructors, we found that the simulations helped tremendously with communicating visual models, fostering conceptual development, illustrating everyday life phenomena that are not visible to the eye, and providing opportunities for interactive engagement in class. We also received positive feedback from the students with regard to how helpful they found the PhET simulations. We found improved student performance on the final exam compared with the previous year.

Development

The PhET Project - an on-going effort to create a suite of interactive simulations and related education resources that aid in the teaching and learning of physics. Our immediate objectives are:

- Continue to develop new simulations and to refine existing ones.
- Accompany each simulation with a tutorial or series of tutorials that provide a means for self-guided discovery of the physics principles.
- Provide resources for educators that include:
  - Examples of learning goals that are well addressed by using the simulations.
  - Lecture versions of each simulation with larger fonts and instructor control over configuration.
  - Examples of use as a lecturing tool including suggestions for interactive lecture demos and peer instruction activities.
  - Examples of homework assignments created to work with the simulations.

Implementation

- In-class/Lecture:
  - As an effective means of communicating the instructors* visual model to the students.
  - As a means for interactive engagement within class using the Peer Instruction Model with simulation-centered ConcepTests of Interactive Lecture Demos.
  - As a complementary learning-support tool for classroom demonstrations.
  - As short pre-class activities to prepare students for class.
- Homework, Recitations, or Labs.
  - As a method of promote active thinking with inquiry-based exercises designed around the simulations.
  - As an alternative to or supplement for traditional introductory physics labs.
- Alternative educational settings.
  - As a way to mix fun and learning in after-school programs, science museums, etc.
  - As a tool to effectively educate and engage the general public into thinking about physics.

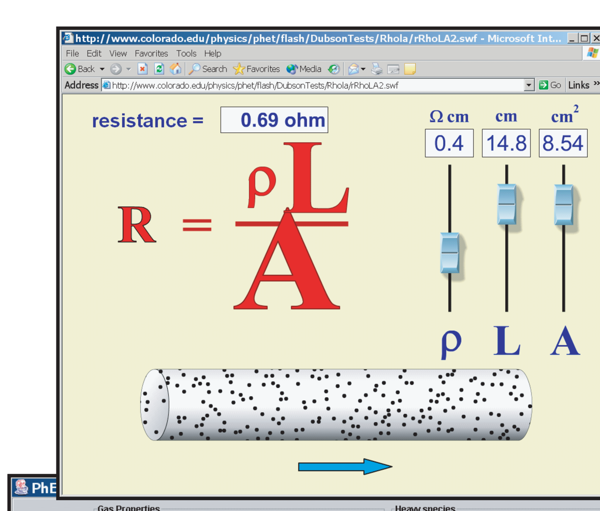
Research

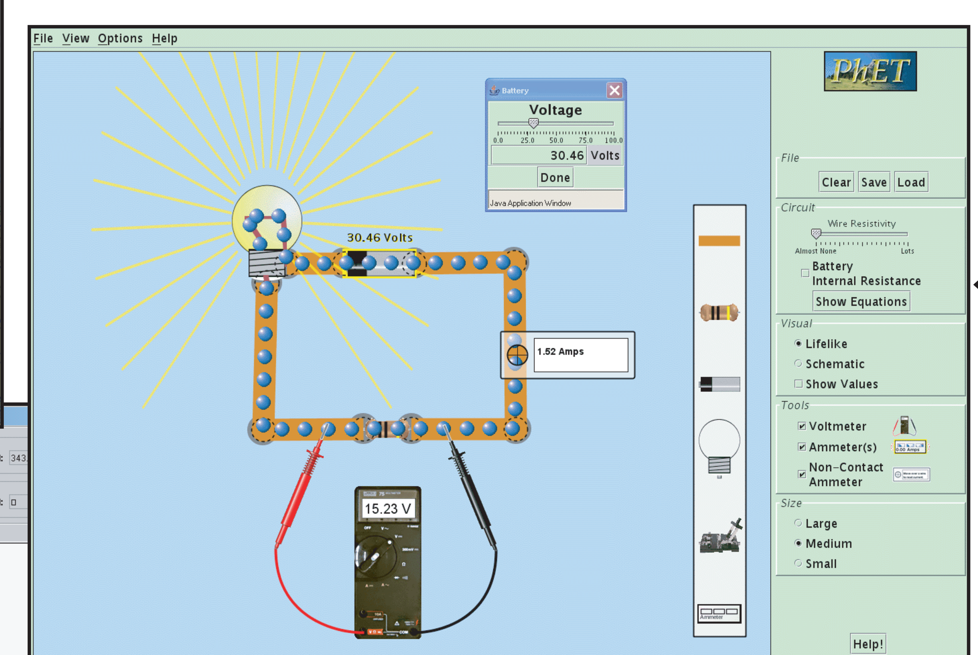
The PhET Project includes a substantial research effort to assess the effectiveness of these interactive simulations in a variety of educational environments, particularly in introductory physics courses and as stand-alone / informal educational tools. Research areas include:

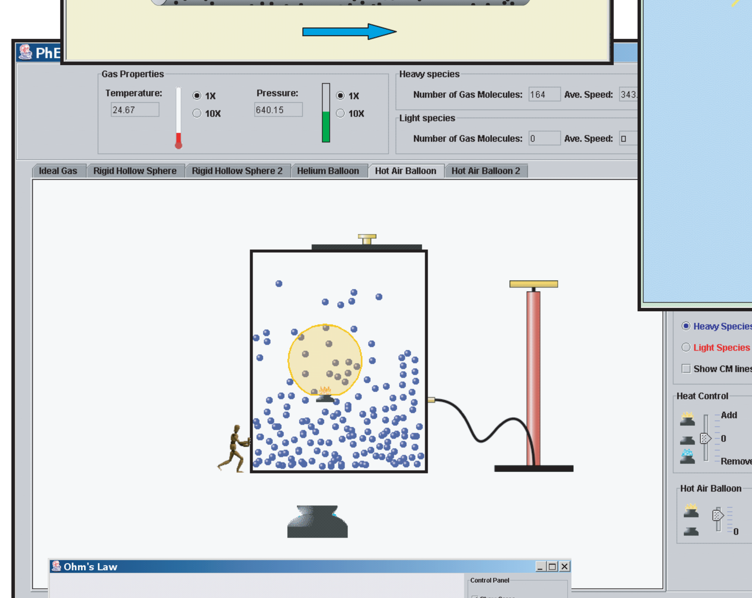
- The simulations effect on students' ability to solve conceptual and quantitative problems.
- Student attitudes and beliefs:
  - about learning physics
  - about their own learning and of the simulations themselves.
- Influences on the effectiveness of the simulations as a learning tool.
  - Student's interaction with the simulation (e.g. guided tutorial vs game-like challenge).
  - The educational setting (e.g. groups vs non-groups) .

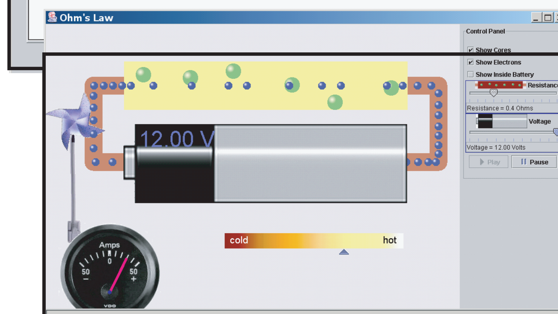
Our Design Philosophy:

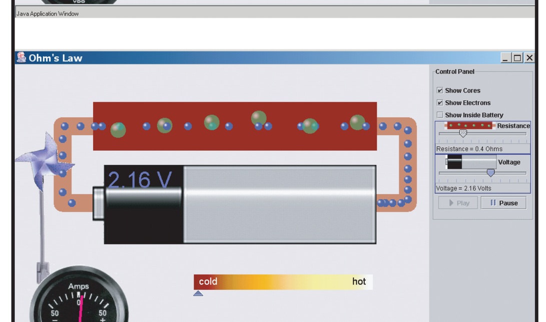
- Emphasize the connection between physics and everyday life.
  - If students perceive the relevance to their lives, they are more likely to invest time in understanding the physics.
  - If you teach physics in the context of everyday life applications, students are more likely to recognize other applications where physics enters their daily lives.
- Facilitate the development of accurate visual and conceptual models of the underlying physical principles.
  - Through simulations, educators can more effectively share the mental pictures scientists have developed for how things work.
  - Interactive simulations of physical phenomena aid in developing accurate conceptual models of the physics.
- Serve as a bridge between conceptual physics and abstract concepts of mathematical models, or between different forms of representation.
  - Interactive simulations providing multiple visual representations of the same physical phenomena can help students recognize these connections and strengthen their overall understanding of the physics.
- Engage students through interactive exploration of the physics and through the creation of fun, game-like challenges.
  - How the student interacts of engages with the simulation can impact their learning and their attitudes towards physics.
  - Open model environment promotes student-driven inquiry.
- Use quantitatively accurate physical models for simulation behavior.
- Make physics accessible to a broader population.
  - Simulations provide an alternative to traditional modes of teaching and learning physics
  - Free, web-based simulations and education resources are valuable to educators.

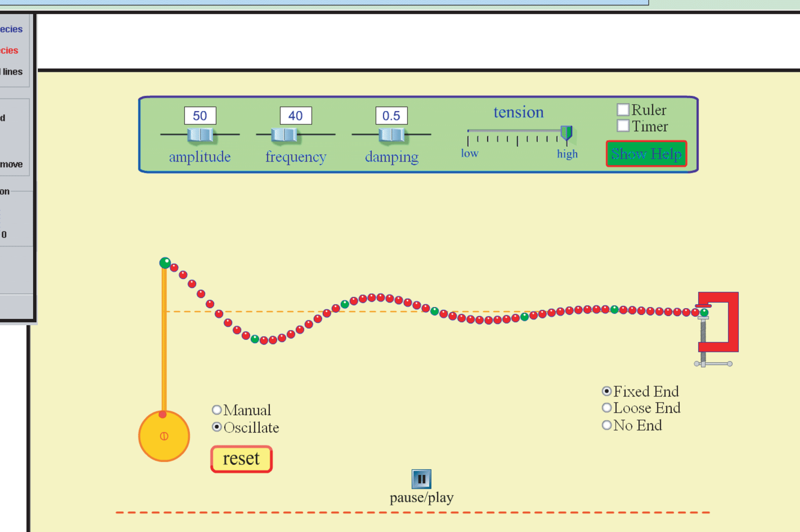


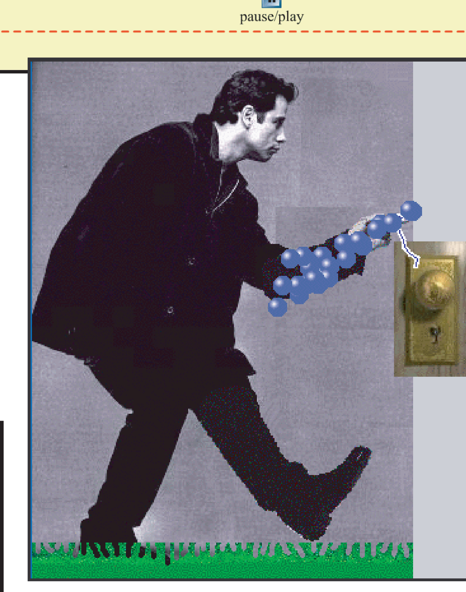












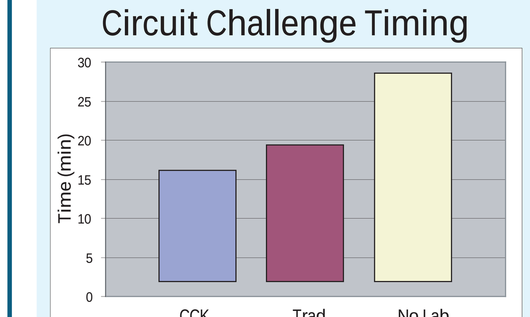
Research:

We conduct research to assess the effectiveness of the PhET simulations in a variety of settings. In one such study, we examined the effect of substituting computer simulations in place of real laboratory equipment in the second semester of a large-scale introductory physics course*.

CCK

- The Circuit Construction Kit (CCK - shown on left) was substituted for real laboratory equipment in 1/3rd of sections.
- Students conducted the same activities using CCK or real laboratory equipment.
- Last 30 minutes of lab time set aside for circuit challenge - same for all students. Students assemble a circuit and describe its behavior.
- Final exam includes 3 conceptual questions on DC circuits.

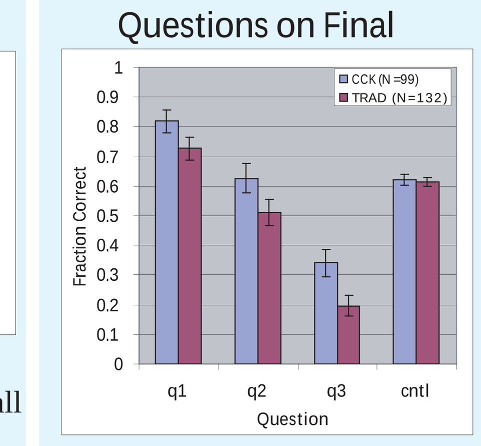
Circuit Challenge Timing



Time for students to build a circuit and write about it. Mean times for all groups plotted.

CCK- group using simulations
Trad - group using traditional equipment
No Lab - group from calculus class, no formal lab experience but had covered challenge material in

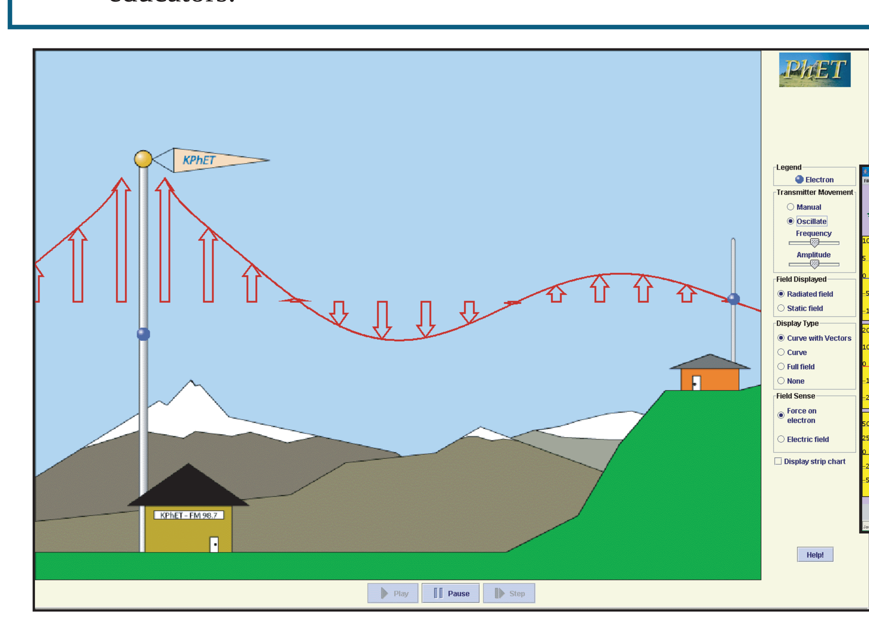
Questions on Final

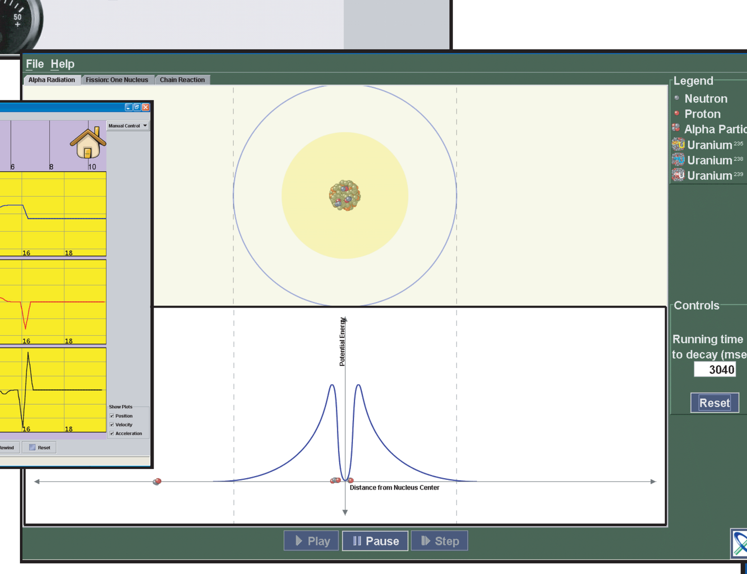


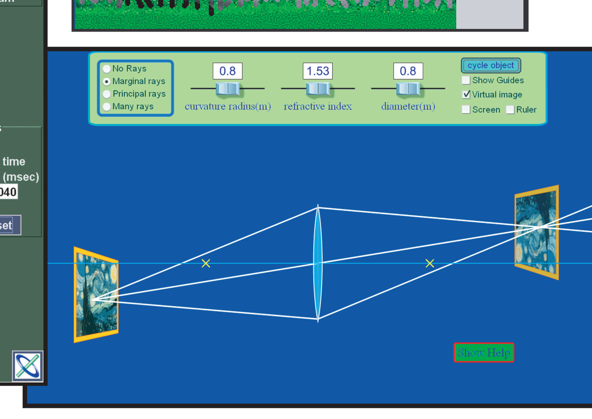
Student achievement on three conceptual circuits questions shown left and the remaining 26 questions on final (ctrl). The mean for all three questions is 0.593 for CCK and is 0.476 for TRAD groups; $p<0.001$

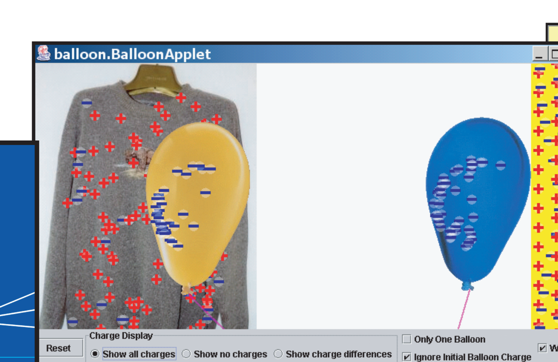
- Conclusion - simulations can replace real lab equipment. Students are shown to master concepts better and have greater skills at assembly of real circuits.

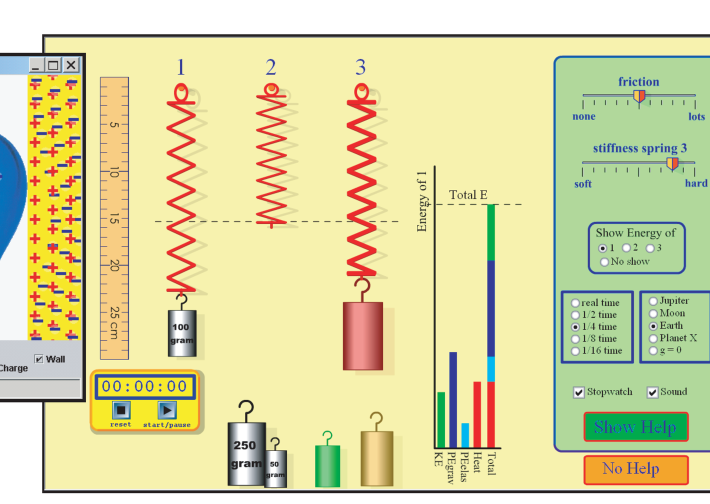
* Finkelstein, ND, Perkins, K, Adams, W, Kohl, P, & Podolefsky, N. Can Computer Simulations Replace Real Laboratory Equipment? presented at the 2004 Physics Education Research Conference











Selection of Programming Technology:

Java:

Selected for simulations that are computationally intensive or are based on complex physical models.

Pros
- One-click accessible from web browsers.
- Java Web Start minimizes downloading.
- Java is an industry-standard, general-purpose language with broad support and great flexibility.

Cons
- Requires more programming savvy.
- Requires development and maintenance of a reusable framework for building simulations to reduce development time.
- Mac support for the latest Java Virtual Machine typically lags behind.

Flash:

Selected for simulations that are not computationally intensive.

Pros
- Runs well from web browsers on both PCs and Macs.
- Small files for quick downloads.
- Quick learning curve and fast development time.
- Language comes with an integrated system for building animations and a framework for building simulations

Cons
- Single-vendor product.
- Simulations must run in a browser, and as a result simulations may not look the same on all platforms

Current PhET Applets:

Force and Motion
Masses & Springs, The Moving Man, Maze Game, Projectile Motion, 2D Motion

Work, Energy, and Power
Ideal Gases & Buoyancy, Conservation of Energy, Bernoulli

Sound and Waves
Sound Interference and the Doppler Effect, Wave on a String

Heat & Thermodynamics
The Greenhouse Effect, Friction

Quantum Phenomena
Nuclear Physics, Lasers

Light and Radiation
Microwaves, Blackbody Radiation, Color Vision & Filters, Geometric Optics

Math Tools
Vector Addition, Equation Grapher

Heat & Thermodynamics
The Greenhouse Effect, Friction, Blackbody Spectrum

Electricity & Circuits
Circuit Construction Kit, Radio Waves, Electric Field Hockey, Balloons & Static Electricity, John Travoltage, Faraday's Law, Electric Field of Dreams, Battery Voltage, Battery-Resistor Circuit, Ohm's Law, Resistance in a Wire, Signal Circuit

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